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Applications of Embedded Resource Accounting to U.S. Water Resources

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U.S. Environmental Protection Agency and Industrial Economics
“Importance of Water”, September 2012, Washington, DC

Why is it difficult to use classical economics to compare different uses of water?

- A public resource; markets are absent or very distorted,
- Without substitute as a basis for life; infinite absolute total value,
- Used in huge quantities; very low marginal value,
- Highly variable in space, time, and quality; scarcity is contextual,
- Difficult to store and transport; high fixed and transaction costs,
- Mostly non-market values and uses; i.e. high externalities, and
- Institutions assume abundance and free access by economic users.

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General goals of this Meeting

1. Summarize existing knowledge about the role and importance of water to the U.S. economy;
2. Provide information that supports private and public sector decision-making, and
3. Identify areas where additional research would be useful.

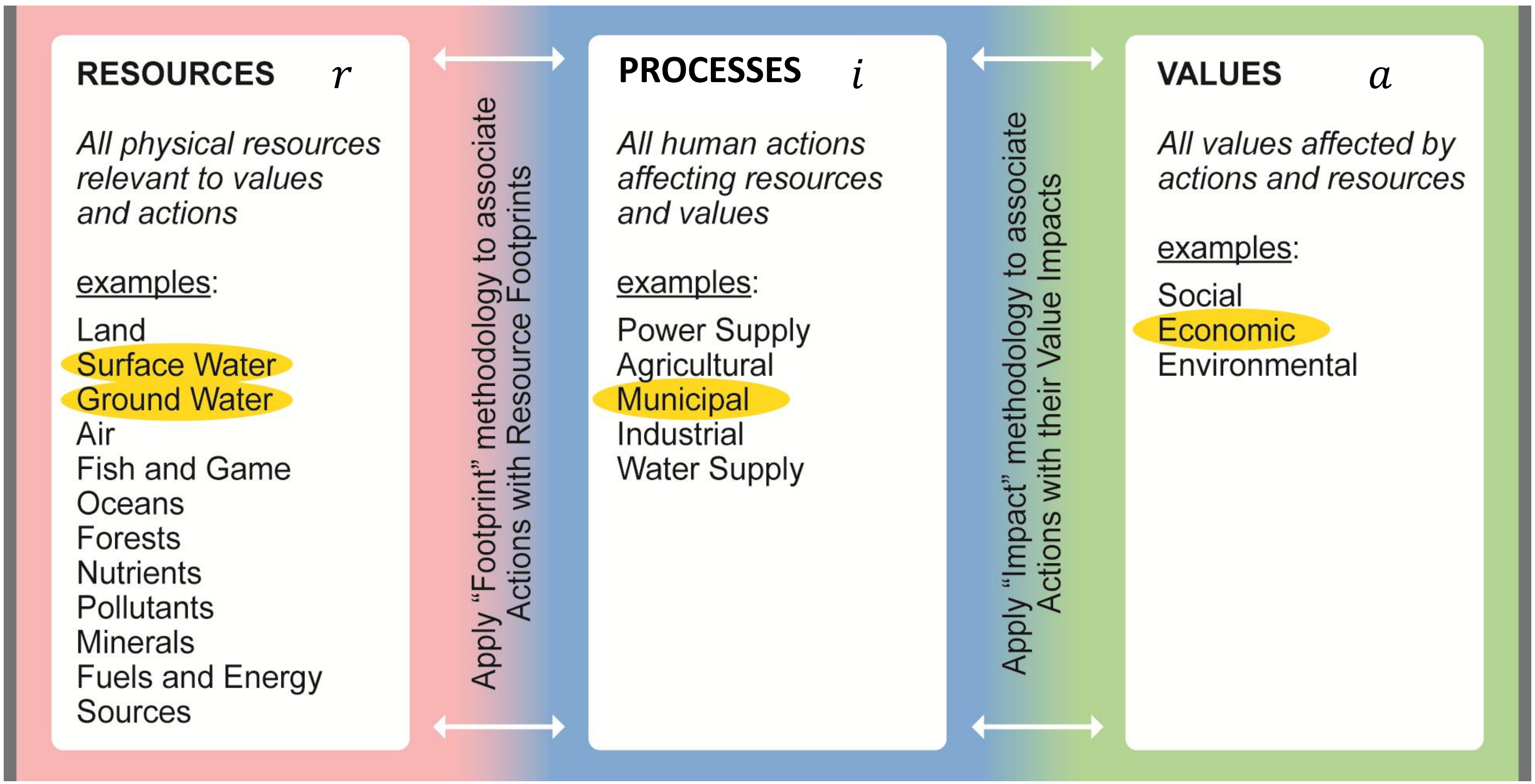
Classical economics can help with these goals, but there may be other approaches that are also useful…

We will review Embedded Resource Accounting and Embedded Values Assessment methods with examples of their applications to water resource issues in the USA

An Alternative: Embedded Values Assessment

Value Intensity (VI) is the ratio of value produced by a process *i* to its Embedded Impact on process *j's* resource stock r_j:

$$VI(i,j,r_j,a) = \frac{A(i,a)}{E(i,j,r_j)}$$



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Comparing EVA with Economics

EVA Disadvantages

- NOT a classical economic method; does not fall under the Theories of Value
- Multiple “values” are not commensurate or additive and must remain independent
- Limited to considering impact on a single resource stock or group of stocks
- Cannot optimize a complete system of value
- Does not consider marginal cost, marginal value, or value added

EVA Advantages

- Readily available I/O data
- Accommodates social and environmental values directly without thorny methods
- Does not require a market
- Compatible with multi-objective methods
- With ERA methods, accounts for both indirect and direct resource footprints
- “Apples to Apples” comparisons of values relative to a single resource footprint
- Directly study role of externality and externalizing resource impacts to solve problems with local scarcity

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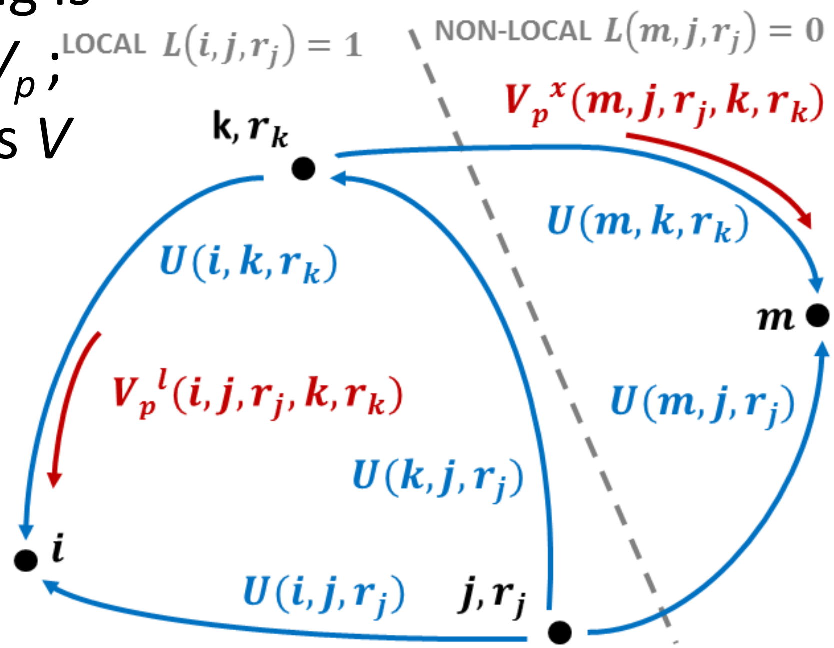
Embedded Resource Accounting

The foundation of Embedded Accounting is the *partial embedded resource impact* V_p; the sum across intermediaries k and r_k is V

$$V_p(i,j,r_j,k,r_k) = \frac{U(i,k,r_k)}{\sum_n U(n,k,r_k)} * U(k,j,r_j)$$



Multiply V_p by *Locality L* or *Externality X* to obtain $V_p^{\,l}$ or $V_p^{\,x}$

$$X(i,j,r) = -[L(i,j,r) - 1]$$

The *Resource Intensity RI* is the ratio of the production of resource r_i to the impact on all resource stocks r_j by process i

$$RI(i,r_i,r_j) = \frac{P(i,ri)}{\sum_j E(i,j,r_j)}$$

*Local and External Versions Exist
** *RI* = 0 if *P* or *E* are zero

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Embedded Resource Accounting

ERA obeys continuity: change ΔS in the state S of stock r_j, is the difference between net production P and net direct impact U:

$$\Delta S(j, r_j)[t] = P(j, r_j)[t] - U(j, r_j)[t]$$

Net Direct Impact U is computed from an Input/Output table or as the difference* between withdrawals W and returns R:

$$U(i, j, r_j) = IO(j, i, r) - IO(i, j, r) = W(i, r_j) - R(i, r_j)$$

*U is nonnegative; $R \leq W$

*Embedded Impact (E)** is the sum of the net direct U and net indirect embedded (or "virtual") impacts V of i on j's r_j:

$$E(i, j, r_j) = U(i, j, r_j) + V^l(i, j, r_j) + V^x(i, j, r_j)$$

*E is a resource footprint, e.g. a water footprint

The sum of E across all impacting processes i is equal to the total net direct impact; each V is offset by an equal and opposite V:

$$\sum_i E(i, j, r_j) = \sum_i U(i, j, r_j) = U(j, r_j)$$

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RI of water embedded in electricity purchased and traded on the Western U.S. Power Grid

Resource Stocks:

Water (Mgal)

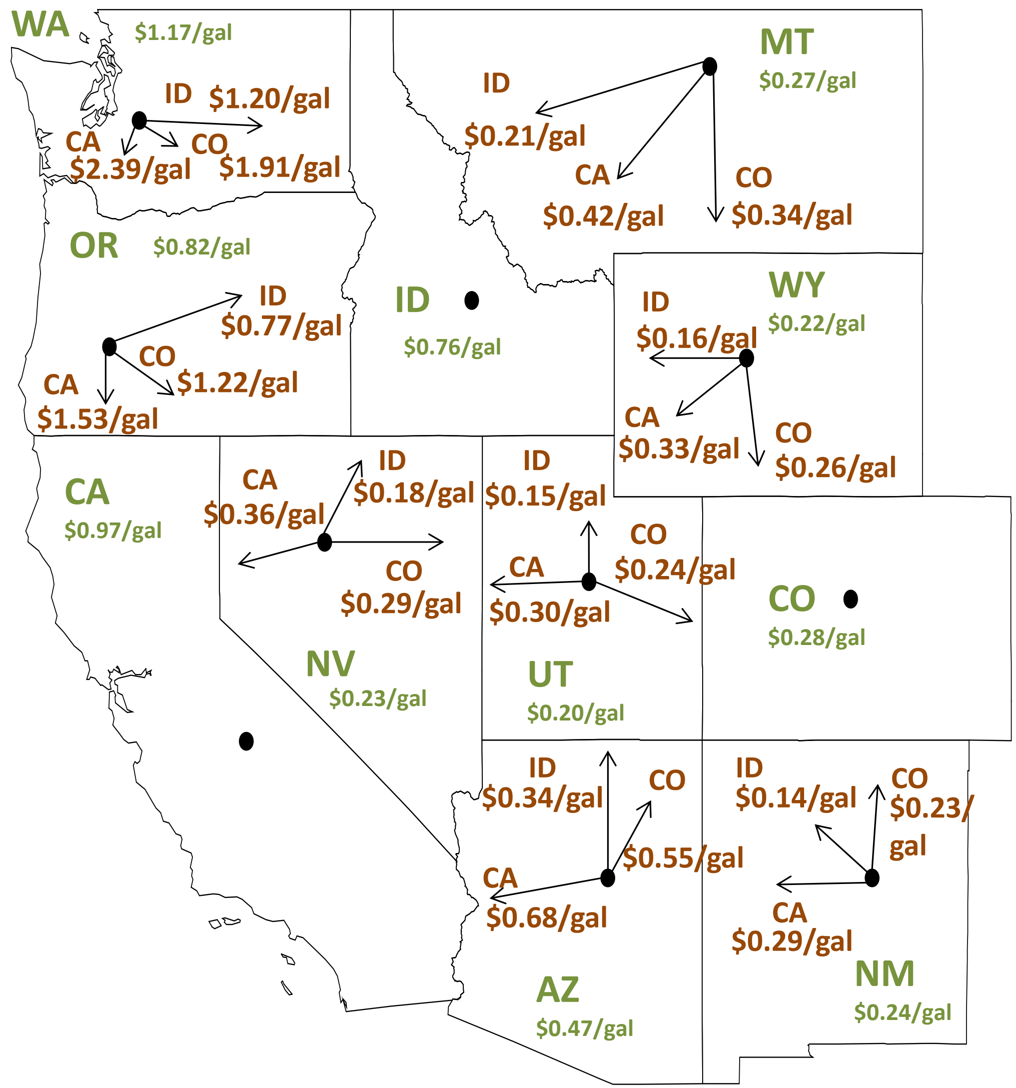
Electricity (MWh)

Dollars ($USD)

Processes:

State kWh Consumers

State kWh Generators



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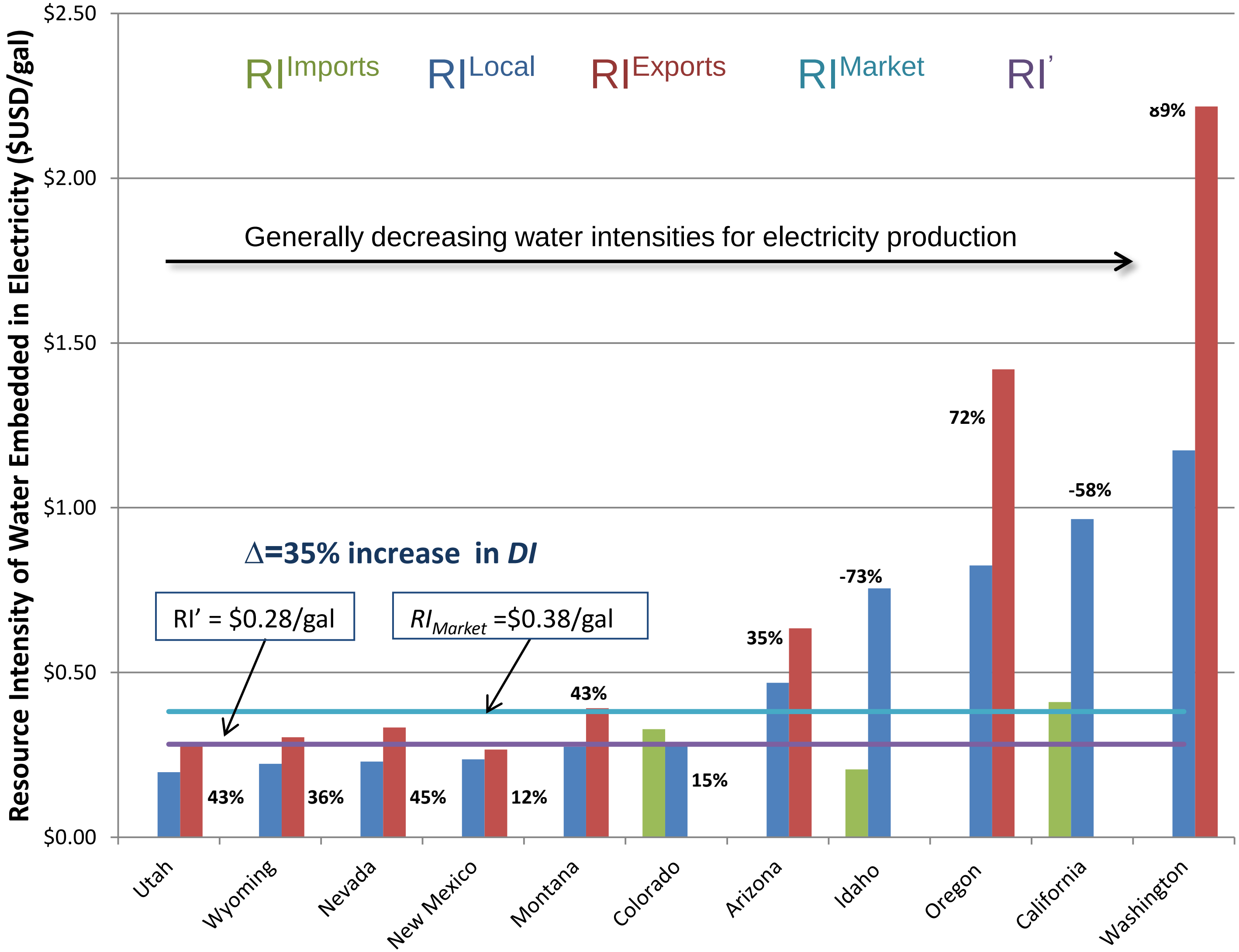
RI of water embedded in electricity purchased and traded on the Western U.S. Power Grid



Higher dollar intensities are generally associated with States that have lower local water intensities per MWh (i.e. less water used per MWh, or more water-efficient generation).

Exporters generally see an increase in dollar intensity compared with local dollar intensity, and

importers generally see a decrease in dollar intensity compared with local dollar intensity.

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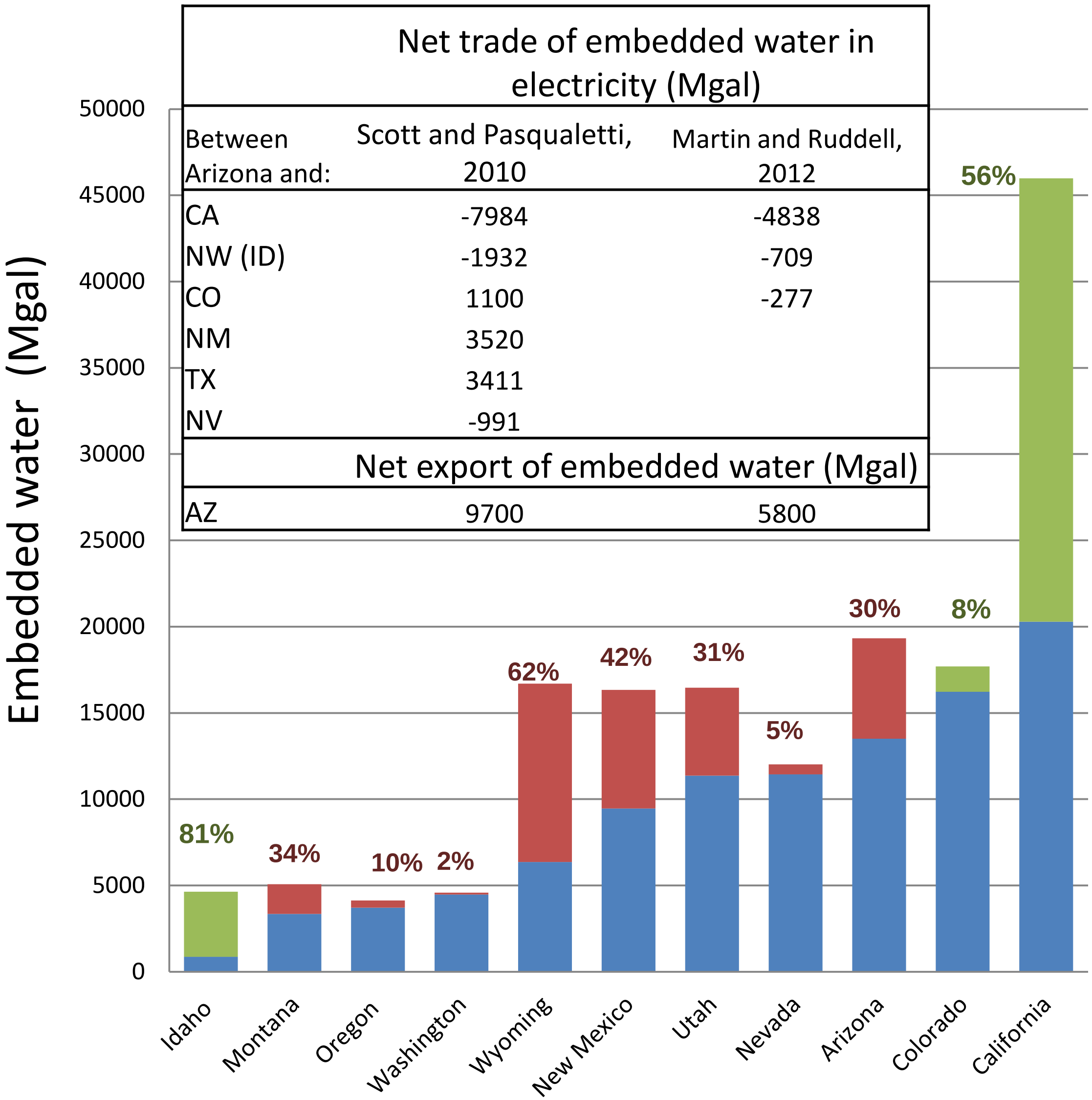
E for the Western Water/Electricity Nexus



Net trade of embedded water in electricity (Mgal)		
Between Arizona and:	Scott and Pasqualetti, 2010	Martin and Ruddell, 2012
CA	-7984	-4838
NW (ID)	-1932	-709
CO	1100	-277
NM	3520	
TX	3411	
NV	-991	
Net export of embedded water (Mgal)		
AZ	9700	5800

External water embedded in imported electricity

Internal water embedded in exported electricity

Internal water embedded in locally consumed electricity

For Production and Consumption processes combined per State*:

V^x_{OUT} = **red** $\quad V^I_{OUT}$ = **blue** or 0

V^x_{IN} = **green** $\quad V^I_{IN}$ = **blue** or 0

U = **red** + **blue**

$$E = U + V^I_{IN} - V^I_{OUT} + V^x_{IN} - V^x_{OUT}$$

Therefore, the "water footprint" is:

E = **green** + **blue**

*See Appendix for V_{IN} and V_{OUT}

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VI for Arizona Cities' Economic Sectors

Resource Stocks:

Arizona Surface Water**

Processes:

Arizona Cities

Values:

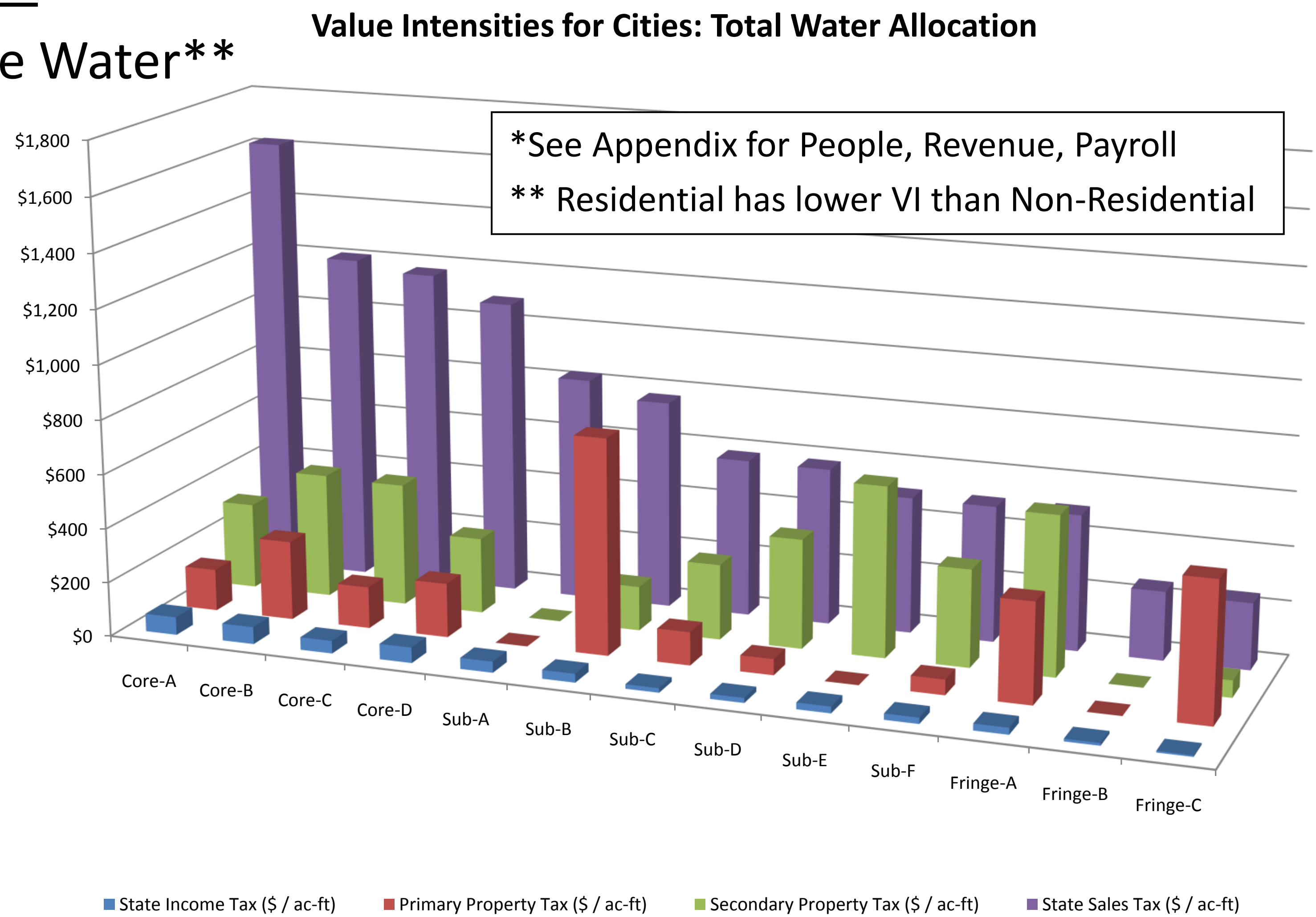
State Tax

Local Tax

People*

Revenue*

Payroll*



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RI for Major Arizona Firms

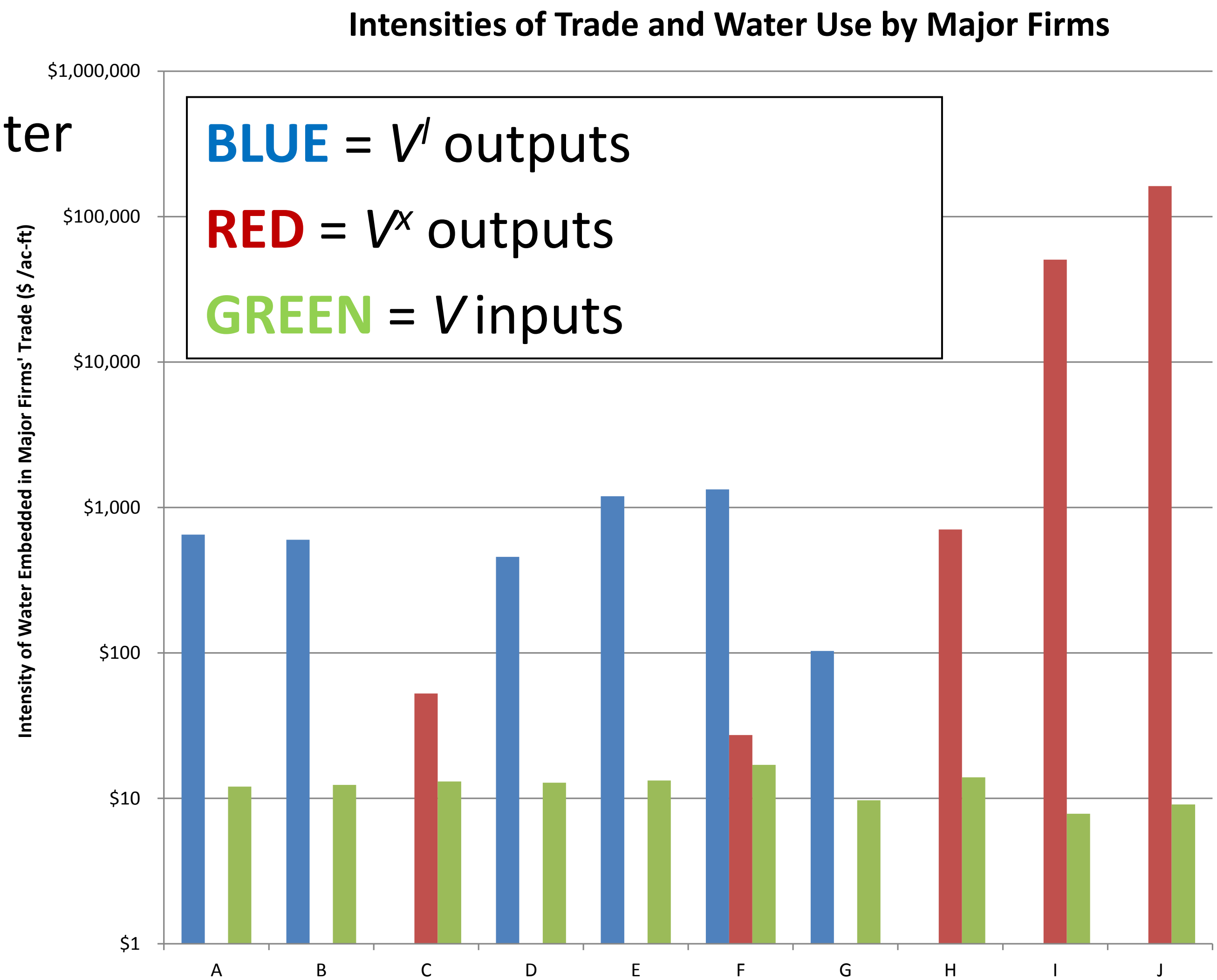
<u>Resource Stocks</u>:

Arizona Surface Water

$ value of trade

<u>Processes:</u>

Arizona Cities



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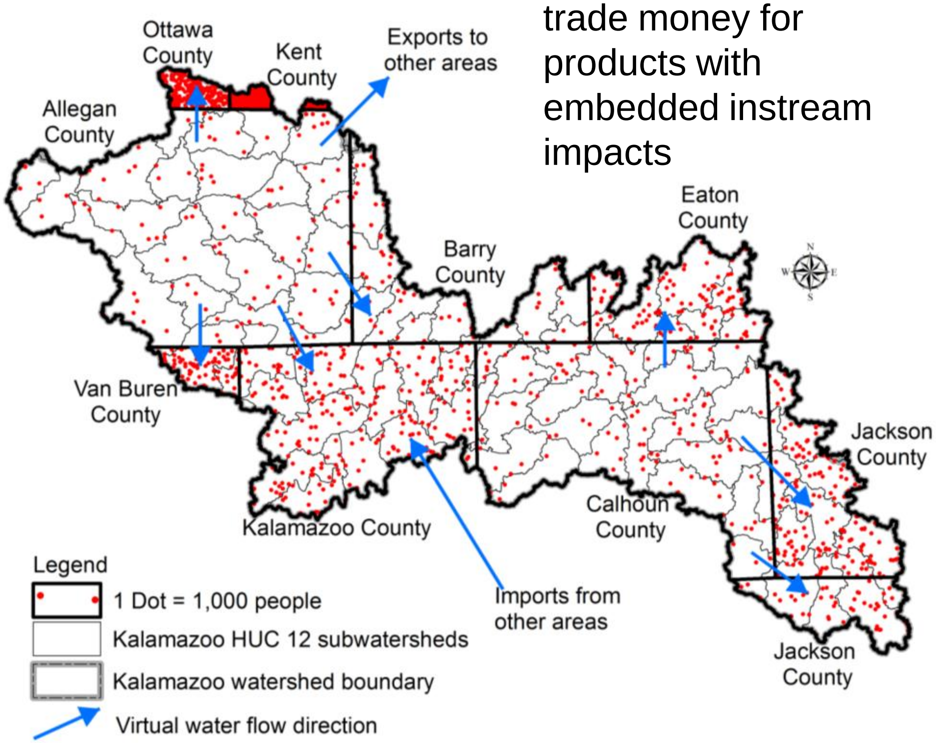
VI for Great Lakes Freshwater Ecosystems

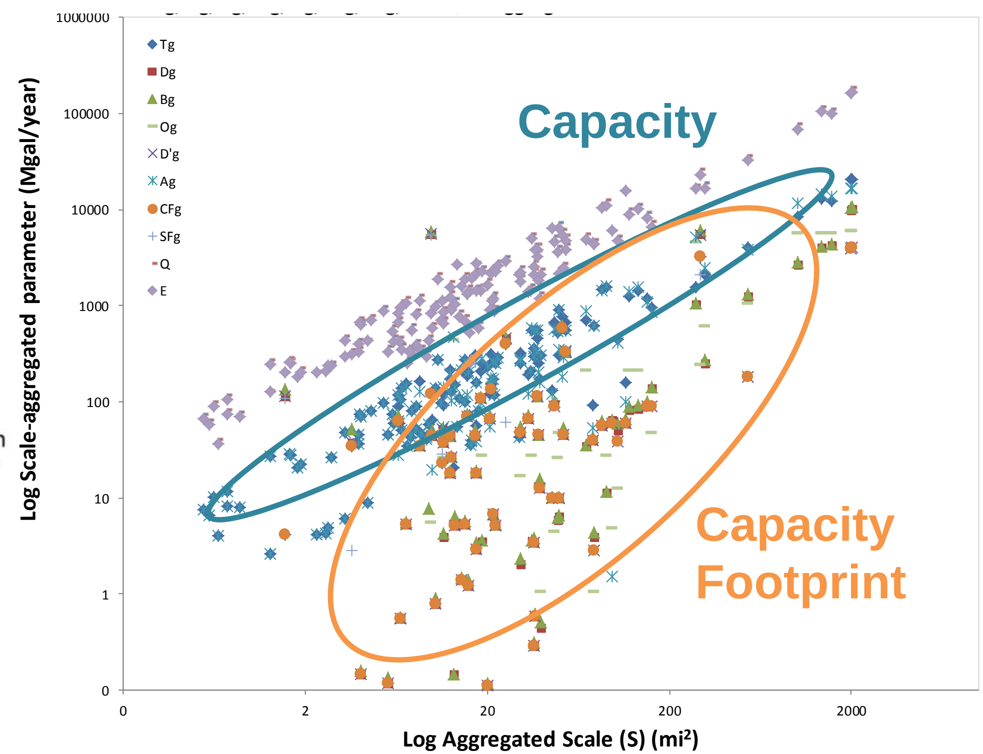
<u>Resource Stocks</u>: Instream Capacity and Ecosystem Flow Requirements

<u>Processes:</u> individual Great Lakes water users (cities, power plants)

<u>Values:</u> Revenue, Taxes, Population, Payroll

Distant consumers trade money for products with embedded instream impacts





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Summary

- EVA and ERA methods reveal patterns in how water is used or substituted in the U.S. economy and how it is associated with the creation of things we value
- Ongoing work on Cities, Watersheds, and Electrical Production is expanding to Agricultural and Extraction sectors
- The exciting opportunity here is to map the embedded flows of water in the U.S. economy nationwide at finer spatial scales and to link findings with scarcity and cost of water

Questions?

Acknowledgements

Vincent C. Tidwell, Sandia National Laboratories

Colleagues and Students, Arizona State University

Staff at Ruddell Environmental

Appendix

IN/OUT V Math

$$X(i,j,r) = -[L(i,j,r) - 1]$$

$$V_{IN}(i,j,r_j) = \sum_{r_k}\left[\sum_{k}\left(\frac{U(i,k,r_k)}{\sum_n U(n,k,r_k)} * U(k,j,r_j)\right)\right]$$

$$V_{OUT}(i,j,r_j) = \sum_{r_k}\left[\sum_{i}\left(\frac{U(i,k,r_k)}{\sum_n U(n,k,r_k)} * U(k,j,r_j)\right)\right]$$

$$V_{IN}^{x}(i,j,r_j) = \sum_{r_k}\left[\sum_{k}\left(\frac{U(i,k,r_k)}{\sum_n U(n,k,r_k)} * U(k,j,r_j) * X(i,j,r_j)\right)\right]$$

$$V_{OUT}^{x}(i,j,r_j) = \sum_{r_k}\left[\sum_{i}\left(\frac{U(i,k,r_k)}{\sum_n U(n,k,r_k)} * U(k,j,r_j) * X(i,j,r_j)\right)\right]$$

$$V_{IN}^{l}(i,j,r_j) = \sum_{r_k}\left[\sum_{k}\left(\frac{U(i,k,r_k)}{\sum_n U(n,k,r_k)} * U(k,j,r_j) * L(i,j,r_j)\right)\right]$$

$$V_{OUT}^{l}(i,j,r_j) = \sum_{r_k}\left[\sum_{i}\left(\frac{U(i,k,r_k)}{\sum_n U(n,k,r_k)} * U(k,j,r_j) * L(i,j,r_j)\right)\right]$$

Example: VI for Cities

Resource Stock:

Arizona Surface Water

Processes:

Arizona Cities

Values:

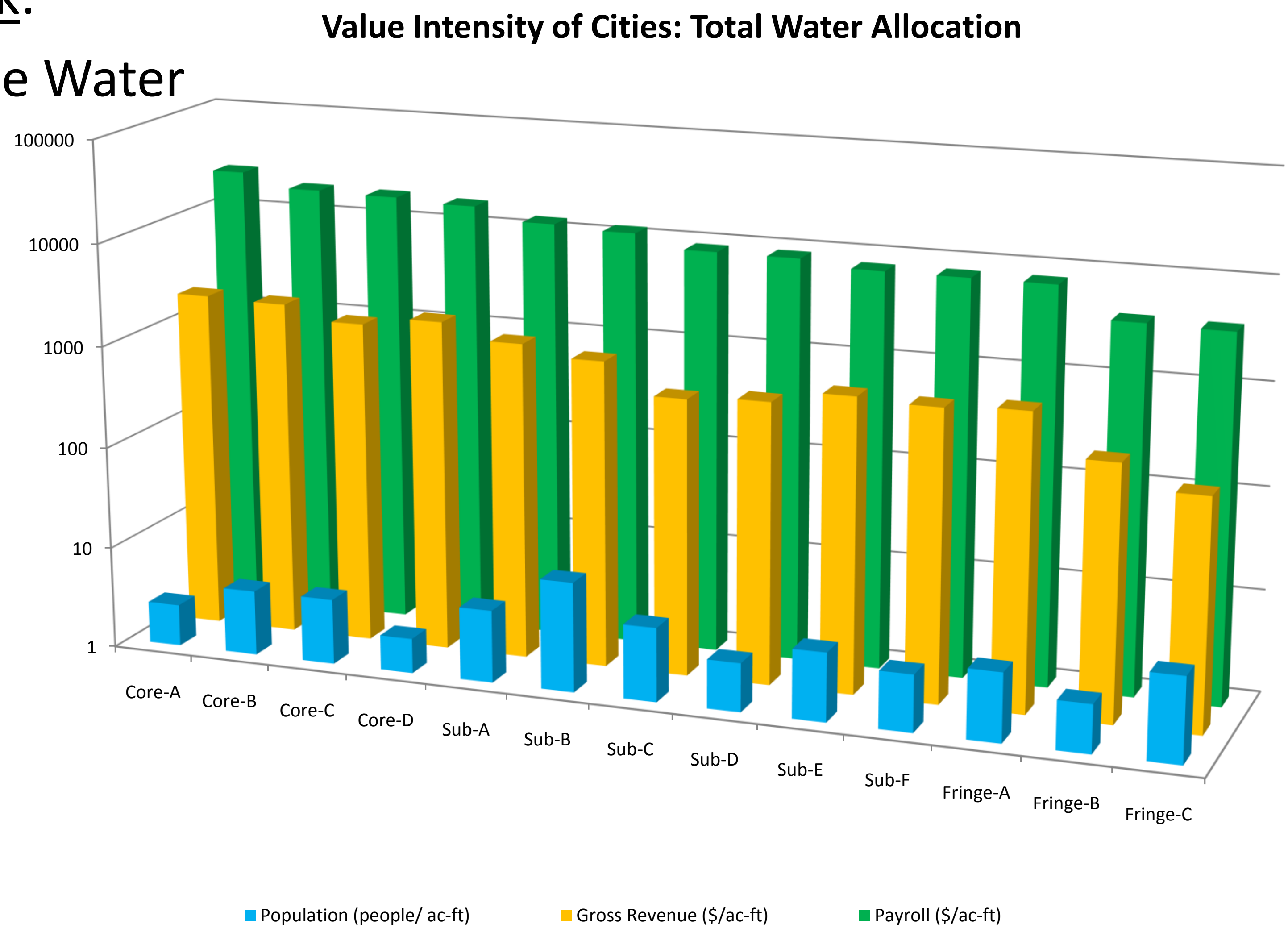
State Tax

Local Tax

People

Revenue

Payroll



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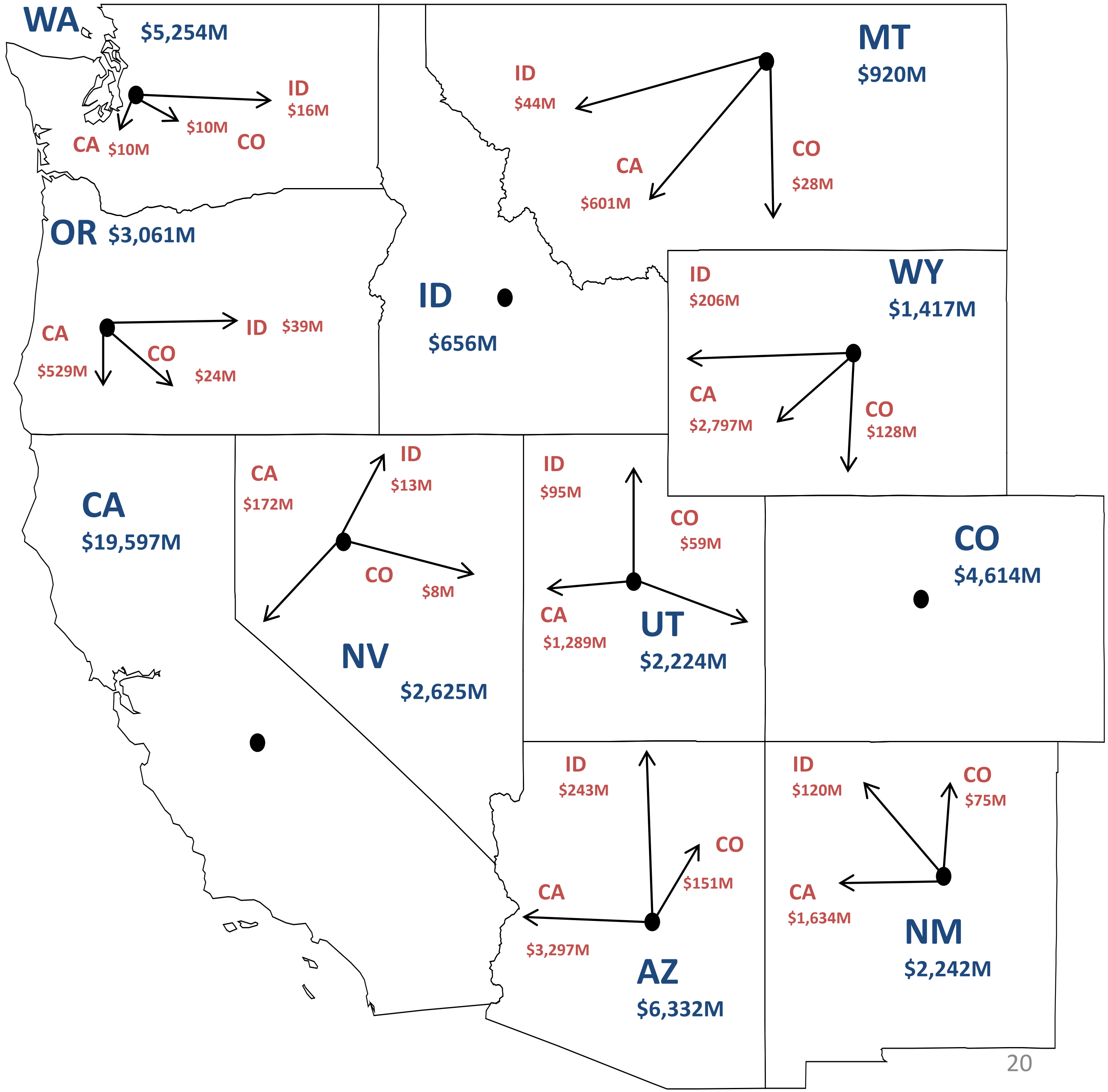
Embedded retail price of electricity transfers



Methods: Data (Resource Intensities)

	Water Intensity (gal/MWh) $\Phi[s]$	Price ($/MWh) $f[s]$
New Mexico	437.25	$103.56
Utah	411.77	$81.35
Wyoming	384.17	$85.57
Colorado	352.66	$100.26
Nevada	349.23	$80.10
Montana	297.32	$81.57
Arizona	183.81	$86.23
California	129.69	$125.26
Idaho	83.31	$62.91
Oregon	82.04	$67.65
Washington	52.52	$61.65

Water intensities calculated using *Sandia National Laboratory Energy/Water Nexus Group* model output data, for year 2020, of total electricity produced and net water consumed at each power plant within each state (EPA 2010, EIA 2005, Kenny et al. 2009, Macknick et al. 2011, Solley et al.1995)

Prices are 2009 averages of retail electric utility prices for all utilities within each state obtained from US Energy Information Administration (EIA 2011a)

- Low prices = incentive to overproduce for electricity export
- High prices = high demand, limited supply, high costs of electricity generation
- Low water consumption intensity = water scarcity/conservation

Martin, E.A. and Ruddell, B.L. 2012. Dollar intensity of water used for electrical energy generation in the western U.S.; An application of embedded resource accounting. Arizona Hydrological Society. September 19, 2012. Phoenix, Arizona.

Methods: Data (Electricity Trade)

	Net Interstate Trade, $T^{NET}[s]$, (MWh)	Gross Export, $T^{O}[s]$, (MWh)	Gross Export Coefficient, $C^{O}[s]$, (%)
Arizona	31,685,245	31,685,245	31.3%
Montana	5,775,543	5,775,543	5.7%
New Mexico	15,7[illegible]	[illegible]	[illegible]
Nevada	1,6[illegible]	[illegible]	[illegible]
Oregon	5,0[illegible]	[illegible]	[illegible]
Utah	12,389,184	12,389,184	12.2%
Washington	2,117,039	2,117,039	2.1%
Wyoming	26,882,529	26,882,529	26.5%
		Gross Import, $T^{I}[s]$, (MWh)	**Gross Import Coefficient, $C^{I}[s]$, (%)**
California	(84,137,000)	84,137,000	83.1%
Colorado	(4,815,000)	4,815,000	4.8%
Idaho	(12,333,000)	12,333,000	12.2%

Scott and Pasqualetti (2010) Reported Gross export of electricity from Arizona = 30,750,700 MWh.

- Trade data is for 2009 using EIA data tables
- T^{NET} is production – consumption within each state
- Total exports must equal total imports summed across network
- 1% reduction in exports due to export to neighboring grid(s)

(EIA 2011a, EIA 2011b)

Methods: Data (Electricity Trade)

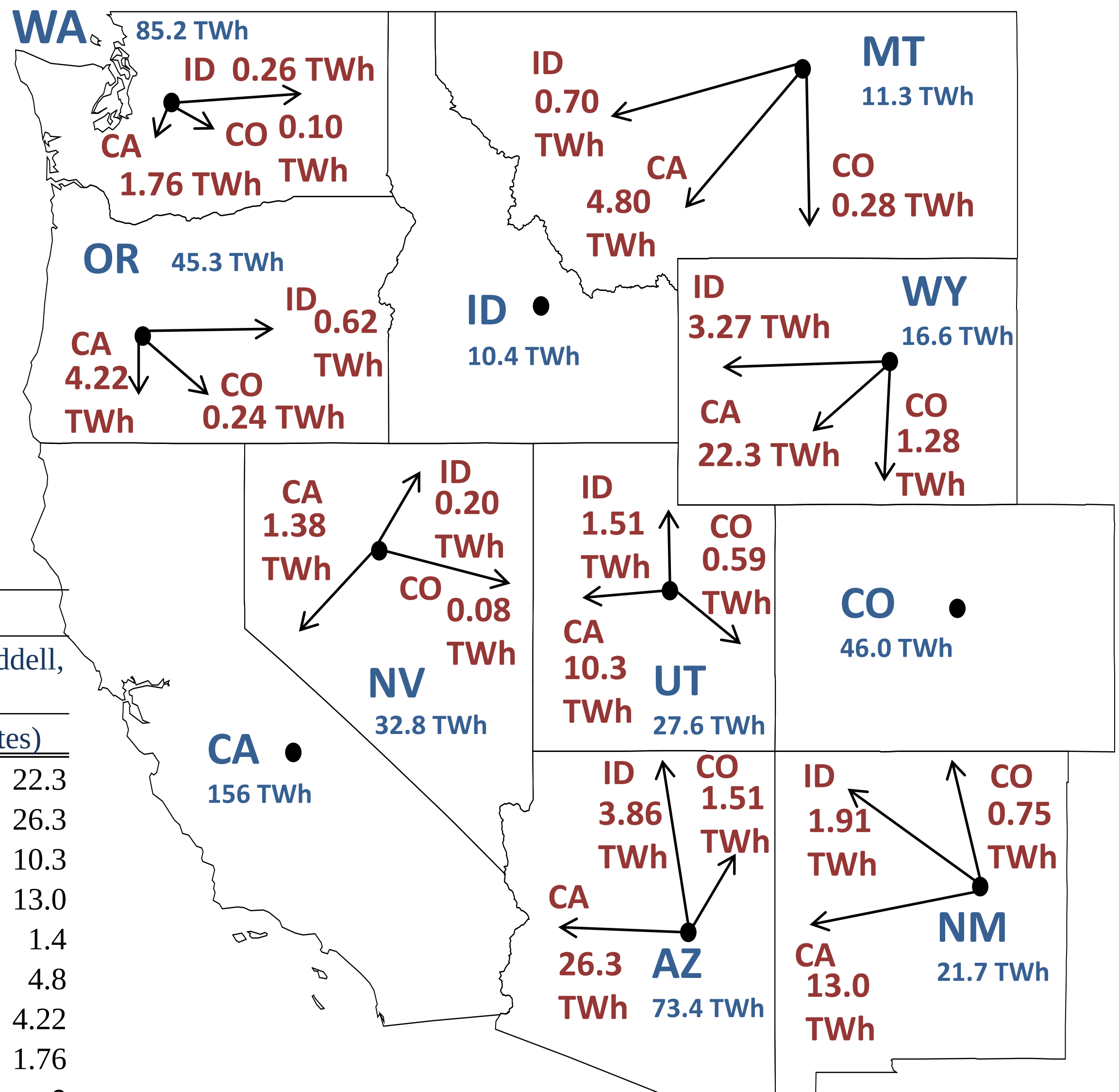
How our numbers compare to 2005 linear optimization study by performed by others. (Marriott et al, 2005)

Net Interstate Trade (TWh)	Marriott and Matthews, 2005 (Year 2000)	Martin and Ruddell, 2012 (Year 2009)
Arizona	20.1	31.7
Montana	11.8	5.8
Nevada	4.8	1.7
New Mexico	12.3	15.7
Oregon	(3.3)	5.1
Utah	10.2	12.4
Washington	1.1	2.1
Wyoming	29.1	26.9
California	(69.1)	(84.1)
Colorado	(3.1)	(4.8)
Idaho	(11.9)	(12.3)

Martin, E.A. and Ruddell, B.L. 2012. Dollar intensity of water used for electrical energy generation in the western U.S.; An application of embedded resource accounting. Arizona Hydrological Society. September 19, 2012. Phoenix, Arizona.

Methods: I/O Table for ERA

- Electricity trade network (TWh)
- Transfer quantities shown for all exporting states to each importing state
- Internally produced and consumed electricity shown for each state in blue
- CA dominates imports consuming 83.1% of traded electricity



Electricity Exports to California

From:	Marriott and Matthews, 2005 (2000 estimates)	Martin and Ruddell, 2012 (2009 estimates)
Wyoming	24.8	22.3
Arizona	20.1	26.3
Utah	10.2	10.3
New Mexico	9.2	13.0
Nevada	4.8	1.4
Montana	0	4.8
Oregon	0	4.22
Washington	0	1.76
Mexico	(2.10)	0

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